

ELECTRON ENERGY DISTRIBUTION FUNCTION IN Ne-H₂ HOLLOW CATHODE DISCHARGE AT INTERMEDIATE PRESSURES

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Abstract. A theoretical study of the Electron Energy Distribution Function (EEDF) in the negative glow of a hollow cathode discharge with cylindrical geometry is proposed. The plasma of a Ne-H₂ Penning Recombination Laser is considered. The EEDF is analyzed in the energy region up to several ionization potentials. The spherical part of the EEDF is calculated under the conditions of high current, intermediate pressures and in a mixture of neon and a molecular gas hydrogen. Using EEDF calculated the rate constant for negative hydrogen ion formation is estimated.

1. Introduction

The electron energy distribution function (EEDF) is an essential characteristic of the plasma kinetics. The knowledge of the EEDF in a hollow cathode discharge (HCD) in a Ne-H₂ mixture at intermediate pressures is important to estimate the role of different elementary processes to the inversion population formation in Penning Recombination Lasers. At low energies the EEDF could be considered as Maxwellian, but as it is well known in HCD it strongly differs from the Maxwellian distribution function at energies higher than the inelastic processes threshold.

Many scientific groups have worked on the problem of the EEDF in HCD. The approach of Kagan et al. [1-6], gives an analytical solution of the Boltzmann equation by means of a simplified physical model. The approach of Peterson [7] and Fetzer et al. [8] consists of numerical solution of the Boltzmann equation. A HCD model has been developed on the basis of a self-consistent model of the negative glow discharge lasers [9]. The Monte Carlo method, by which the three-dimensional motion of electrons can be traced, was used to calculate the EEDF for the electrons of energies larger than the lower excitation energy of helium atoms in HCD [10].

According to the conventional model of HCD the electrons emitted from the cathode by ion bombardment are accelerated in the cathode dark space up to energies corresponding to the cathode fall potential. Then they penetrate the negative glow region losing their energy mainly by ionizations and excitations. The direct ionization, as it is shown in [11, 12], plays an important role in the formation of EEDF and also should be taken into account.

The electron beam from the cathode dark space, the superelastic collisions, hemi-ionizations and the Penning ionization could substantially enrich EEDF in HCD and in the afterglow plasma. Detailed studies concerning the EEDF formation due to these processes and in local and nonlocal regime are made in [11-14].

In the present study the EEDF in a Ne-H₂ high voltage HCD with a cylindrical geometry operating at intermediate pressure is analyzed in the energy region from zero to H₂ dissociation energy E_{diss} (the threshold for the inelastic processes) and from E_{diss} to the energy, where the elastic electron scattering becomes anisotropic, i. e. to the energies of several ionization potentials of the hydrogen molecule.

In the case of the Ne-H₂ Penning Recombination Laser, despite of the short current pulses (2-3 μs), there exists a quasi-equilibrium among the electrons, so the temporal derivative in the kinetic equation can be neglected.

The spherical part of the EEDF is calculated under the conditions of high current, intermediate pressures and in the presence of a molecular gas. The estimations show that in our conditions the superelastic collisions and hemiionizations could be neglected compared to the Penning ionization and in this work they are not taken into account.

In the presence of a molecular gas a vibrational and a rotational level excitation of H₂ molecules takes place. These processes are important not only for the values of electron temperature and electron density, but also for the EEDF formation below and near the dissociation threshold.

For the calculation of EEDF in our conditions the vibrational and rotational excitation, direct and Penning ionization are considered.

2. Isotropic Part of EEDF

For the calculation of EEDF the two-term Legendre polynomial expansion is used. In a cylindrical geometry the equation for the isotropic part of the EEDF f_0 can be written in the form [13]:

$$\frac{1}{r} \frac{\partial}{\partial r} \left(v D_r \frac{\partial f_0}{\partial r} \right) + \frac{\partial}{\partial \epsilon} \left(v D_\epsilon \frac{\partial f_0}{\partial \epsilon} + V_\epsilon f_0 \right) + S_{\text{ion}}^* + S_{\text{pen}}^* = S_{\text{in}}^* \quad (1)$$

where $D_\epsilon = D_E + D_m + D_e + D_{\text{rot}} + D_{\text{vib}}$ and $V_\epsilon = V_m + V_e + V_{\text{rot}} + V_{\text{vib}}$ are the coefficients of diffusion and of dynamic friction in the energy space for the following: electron-molecular (m) and electron-electron (e) collisions, rotational (rot) and vibrational (vib) excitation of the H₂ molecules, respectively. Here $D_r = \lambda v/3$ is the coefficient of the free electron diffusion and v is the electron velocity. $\lambda = \frac{1}{N\sigma_{\text{tot}}}$ is the length of mean free electron path, where σ_{tot} is the total cross-section for elastic and

inelastic collisions with H₂ molecules. The third and the fourth terms in (1) represent the electron yield as a result of the direct and Penning ionization, respectively. The direct ionization is due to the beam of primary electrons accelerated in the cathode region and entering the negative glow. The right hand of the Eq. (1) represents the changes in the electron energy as a result of the inelastic processes.

In this turn [15]

$$D_E = 2 \frac{\varepsilon^{3/2} e^2 E^2}{3m^2 \nu_{em}}, \quad (2a)$$

$$V_m = \varepsilon^{3/2} \delta \nu_{em}; \quad D_m = T_g V_m, \quad (2b)$$

$$V_e = 2\varepsilon^{3/2} \nu_{ee} A_0(\varepsilon) T_e; \quad D_e = 2\varepsilon^{3/2} \nu_{ee} A_0 \varepsilon, \quad (2c)$$

$$V_{rot} = \sqrt{\varepsilon} E_{rot} \nu_{rot}; \quad D_{rot} = T_g V_{rot}, \quad (2d)$$

$$V_{vib} = \sqrt{\varepsilon} E_{vib} \nu_{vib}; \quad D_{vib} = 0 \quad (2e)$$

where ν_{em} , ν_{ee} , ν_{rot} and ν_{vib} are electron-molecule and electron-electron collision frequencies and rotational and vibrational excitation frequencies of H₂ molecules, respectively; E_{rot} and E_{vib} are the energy thresholds of rotational and vibrational excitation of H₂ molecule, respectively; T_g is the gas temperature and $\delta = m_e/M_{H_2}$ is the mass ratio of the electron and H₂ molecules and ε is the total energy. A_0 is a function of f_0 , but with 15% accuracy it can be expressed, using the relation [16]:

$$A_0(x) = \begin{cases} 0.385x & \text{at } x \leq 2.6 \\ 1 & \text{at } x > 2.6 \end{cases}, \quad \text{where } x = \frac{\varepsilon}{T_e}.$$

The excitation from vibrational level $v = 0$ to vibrational level $v = 1$ is only considered. The estimations show that the population of the vibrational level $v = 0$ is much higher than the population of the vibrational level $v = 1$ and the deexcitation from $v = 1$ to $v = 0$ can be neglected.

At energies $\varepsilon \gg E_{vib}$ the collisional term

$$S_{vib}^* = \sqrt{\varepsilon + E_{vib}} \nu_{vib} (\varepsilon + E_{vib}) f(\varepsilon + E_{vib}) - \sqrt{\varepsilon} \nu_{vib}(\varepsilon) f(\varepsilon) \quad (3)$$

could be decomposed in a series on a power E_{vib}/ε [14, 15]. Neglecting the terms of the second and higher order, for S_{vib}^* we obtain:

$$S_{vib}^* = \frac{d}{d\varepsilon} (\sqrt{\varepsilon} \nu_{vib}(\varepsilon) f(\varepsilon)). \quad (4)$$

It should be noticed that (2e) follows from (4).

The terms representing the electron yield due to direct and Penning ionization are:

$$S_{ion}^*(\varepsilon) = \Gamma_{ion} R_{ion}(\varepsilon) \quad (5)$$

$$S_{pen}^*(\varepsilon) = \Gamma_{pen} R_{pen}(\varepsilon). \quad (6)$$

Here Γ is the intensity of the sources and R is their energy distribution normalized to unity [11]:

$$\Gamma_{\text{ion}} = \frac{i}{e} \frac{1}{V}, \quad R_{\text{ion}}(\varepsilon) = 2E_{\text{diss}}(\varepsilon + E_{\text{diss}})^2, \quad (7)$$

$$\Gamma_{\text{pen}} = k_{\text{pen}}[\text{H}_2][\text{Ne}^*], \quad R_{\text{pen}}(\varepsilon) = \delta(\varepsilon - E_{\text{pen}}), \quad (8)$$

where i is the discharge current in A, e is the electron charge, V is the volume of the active media, k_{pen} is the rate constant for Penning ionization, E_{pen} is the energy on electrons, created through Penning ionization and $[\text{H}_2]$ and $[\text{Ne}^*]$ are H_2 molecules density and Ne excited state populations respectively. The Ne(1s) and Ne(2p) levels are considered as sources of Penning electrons.

The term R_{ion} represents the distribution of the secondary electrons generated in ionizing collisions and it is derived from the ionization cross-section. We use R_{ion} in the form (7), proposed in [11, 12].

The term R_{pen} could be taken in the form of δ function. For the problems of the plasma kinetics it is often possible to neglect the real distribution of R_{pen} , because the fine structure in the Penning electron spectrum is not so important as the solution of the (1) contains an integral expression R_{pen} .

The EEDF formation is strongly influenced by the ratio between the radial gradient term of f_0 and the term, corresponding to the elastic and inelastic processes. This ratio is determined by the relaxation parameter $k(\varepsilon)$ [13]

$$k(\varepsilon) = (\nu_{\text{ee}} + \delta\nu_{\text{em}} + \nu_{\text{vib}} + \nu_{\text{rot}})\tau_{\text{diff}}. \quad (9)$$

The relaxation parameter itself expresses the correlation between the energy relaxation length λ_ε and the hollow cathode radius R .

At $k(\varepsilon) \ll 1$ (nonlocal regime) the term with the radial gradient of f_0 is essential. As far as the diffusion of electrons is faster than their energy relaxation by electron-electron and electron-molecular interactions, the EEDF in a given space region is determined not only by the plasma parameters in this region, but also by the whole volume. In the case the EEDF depends both on the space coordinate and on the total electron energy $\varepsilon = W + e\Phi(r)$, where W is the kinetic energy, e is the charge of the electron and $\Phi(r)$ is the radial space charge potential. The method of EEDF calculation in nonlocal regime is proposed in several papers [11-13, 17].

At $k(\varepsilon) \gg 1$ (local regime), e. g. at high pressure or high electron density, the ambipolar space charge potential could be neglected. The term with the radial gradient of f_0 could be neglected in the kinetic equation and EEDF has to be calculated in a local approximation. In this case the EEDF is determined by the local plasma parameters in each point and depends only on the kinetic energy of the electron at that point. Then the total energy ε can be replaced by the kinetic energy W . Therefore the EEDF could be considered as independent from the coordinate for this energy.

In our particular case at intermediate pressures (10-40 Torr) and high electron densities ($1-5 \times 10^{14} \text{ cm}^{-3}$), $k(\varepsilon) \gg 1$. Hence the EEDF should be calculated in a local approximation.

3. EEDF in the Elastic Region

In local approximation the kinetic equation in the energy region from zero to the H₂ dissociation energy has the form:

$$\frac{d}{d\varepsilon} \left(v D_\varepsilon \frac{df_0}{d\varepsilon} + V_\varepsilon f_0 \right) + \Gamma_{\text{ion}} + R_{\text{ion}} + \Gamma_{\text{pen}} + R_{\text{pen}} = 0. \quad (10)$$

The solution of (10) can be written as

$$f = f_{\text{Maxw}} + f_{\text{ion}} + f_{\text{pen}} \quad (11)$$

where f_{Maxw} is the EEDF of slow electrons obtained when the electron sources are not taken into account, f_{ion} and f_{pen} are the solutions of (10) for the ionization and Penning electron sources, respectively.

The Maxwellian part of the EEDF f_{Maxw} has been studied in several papers [11-13, 15-17]. At $\varepsilon < E_{\text{diss}}$ the Maxwellian function has the form:

$$f_{\text{Maxw}}(\varepsilon) = (2\pi T_e)^{-3/2} n_e \exp \left(-\frac{\int_0^\varepsilon d\varepsilon'}{T(\varepsilon')} \right) + C_1 \quad (12)$$

where $T(\varepsilon) = D_\varepsilon/V_\varepsilon$ is the characteristic temperature for electrons of energy ε and usually $T(\varepsilon) \cong T_e$. The form of f_{Maxw} above the threshold E_{diss} depends on the ratio between the elastic and inelastic interactions [13, 15]. If the inelastic processes do not play a significant role, f_{Maxw} remains in the form (12) with $C_1 = 0$. For intensive inelastic processes a strong depletion of the EEDF above the threshold (in our case the dissociation of the H₂ molecules) occurs. The so-called "black wall" approximation takes place and $f_{\text{Maxw}}(\varepsilon_1) = 0$. In this case f_{Maxw} has the form:

$$f_{\text{Maxw}}(\varepsilon) = (2\pi T_e)^{-3/2} n_e \left[\exp \left(-\frac{\int_0^\varepsilon d\varepsilon'}{T(\varepsilon')} \right) - \exp \left(-\frac{\int_0^{\varepsilon_1} d\varepsilon'}{T(\varepsilon')} \right) \right]. \quad (13)$$

The Nonwaxwellian part of the EEDF could be easily found assuming that $T(\varepsilon) \ll E_{\text{pen}}, E_{\text{diss}}$. In HCD this case usually takes place. Neglecting the term $D_\varepsilon \frac{df_0}{d\varepsilon}$, e. g. $T(\varepsilon) \ll \varepsilon$ we can find the partial solution of the Eq. (10) with terms R_{pen} and R_{ion} in the right hand of the equation. For f_{pen} and f_{ion} we obtain [11, 13]:

$$f_{\text{pen}}(\varepsilon) = \Gamma_{\text{pen}} \Theta \frac{E_{\text{pen}} - \varepsilon}{V_\varepsilon} \quad (14)$$

$$f_{\text{ion}}(\varepsilon) = \Gamma_{\text{ion}} \frac{E_{\text{diss}} - \varepsilon}{(E_{\text{diss}} + \varepsilon)V_\varepsilon} \quad (15)$$

where Θ is the Heavyside function.

The distribution of fast electrons in the EEDF depends on the relaxation mechanism of these electrons. Assuming that stepwise processes with energy threshold ΔE and

frequency ν_c takes place, the relaxation of the fast electrons is determined by the ratio [13]:

$$\alpha = \frac{\nu_c(\varepsilon + T(\varepsilon))T(\varepsilon)}{(\nu_{ee}(\varepsilon) + \delta\nu_{ea}(\varepsilon))\varepsilon} \Big|_{\varepsilon=\Delta E} \quad (16)$$

The most typical is the situation when $\alpha \ll 1$. In this case the generated fast electrons relax on electron-electron or electron-molecule collisions, creating a continuous electron spectrum in the region $\varepsilon \ll E_{\text{pen}}$ and $\varepsilon < E_{\text{diss}}$ for Penning ionization and direct ionization respectively.

In the other case $\alpha \gg 1$, the generated fast electrons relax through stepwise processes. As a result the energy loss is not quasi continuous but discrete with a step equal to the threshold ΔE . In our case it is assumed that stepwise processes could be neglected (e. g. $\alpha \ll 1$) and f_{ion} and f_{pen} has a continuous spectrum below their threshold energies.

It is of interest to calculate the energy ε_0 for which the Maxwellian part of the EEDF is approximately equal to the part, formed by fast electrons

$$f_{\text{Maxw}}(\varepsilon_0) \cong f_{\text{pen}}(\varepsilon_0) + f_{\text{ion}}(\varepsilon_0) \quad (17)$$

The calculations show that $\varepsilon \cong 2$ eV. So f_{ion} and f_{pen} play an important role at energies $\varepsilon_0 > 2$ eV. For energies $\varepsilon_0 < 2$ eV the EEDF is Maxwellian and the assumption $\varepsilon \gg T_e$ used for calculating both f_{ion} and f_{pen} is correct.

In summary the complete EEDF is Maxwellian at low energy region up to energies of several $T(\varepsilon)$ and has the step-wise form for energies $\varepsilon \gg T(\varepsilon)$. From the results obtained above it follows that in the region $\varepsilon \gg T(\varepsilon)$ the Penning ionization and direct ionization could substantially enrich the EEDF by fast electrons. This effect is expressed most clearly in currentless plasma or HCD, when low electron temperature takes place and at energies of several T_e and above the EEDF is determined completely by both processes.

4. EEDF in the Inelastic Region

In the energy region above the H_2 molecules dissociation threshold the inelastic processes are dominant. Only ionization, dissociation and vibrational level excitation are taken into account. The equation for EEDF in the inelastic region at energies $\varepsilon > E_{\text{diss}}$ has the form:

$$S_{\text{ion}}^*(\varepsilon) + S_{\text{diss}}^*(\varepsilon) + S_{\text{vib}}^*(\varepsilon) \cong 0 \quad (18)$$

For energies $\varepsilon \gg E_{\text{ion}}$, where $E_{\text{ion}} = 15.4$ eV is the ionization potential of H_2 , $S_{\text{diss}}^*(\varepsilon) = 0$ and $S_{\text{vib}}^*(\varepsilon) = 0$ and the equation can be rewritten in the form:

$$S_{\text{ion}}^*(\varepsilon) = 0 \quad (19)$$

The collision term

$$S_{\text{ion}}^* = \sqrt{\varepsilon + E_{\text{ion}}}\nu_{\text{ion}}(\varepsilon + E_{\text{ion}})f(\varepsilon + E_{\text{ion}}) - \sqrt{\varepsilon}\nu_{\text{ion}}(\varepsilon)f(\varepsilon) \quad (20)$$

could be decomposed in a series on a power of $\frac{E_{\text{ion}}}{\varepsilon}$ and neglecting the terms of higher order, for (19) we obtain:

$$\frac{d}{d\varepsilon} (E_{\text{ion}} \nu_{\text{ion}}(\varepsilon) \sqrt{\varepsilon} f(\varepsilon)) = 0. \quad (21)$$

The solution has the form:

$$f_{\text{ion}}(\varepsilon) \cong \frac{I_0}{E_{\text{ion}} \nu_{\text{ion}}(\varepsilon) \sqrt{\varepsilon}} \quad (22)$$

where I_0 is the flux of the primary electrons, entering the negative glow. In the diffusion regime neglecting the recombination, I_0 is connected directly with the current i and voltage U through the relation [6]

$$I_0 = \frac{i}{e} \frac{1}{V} \frac{1}{1 + k_i} \quad (23)$$

where V is the volume of the active media, $k_i = \frac{U}{E_{\text{ei}}}$ is the number of the ionization which the primary electron having energy U creates in the negative glow and E_{ei} is the energy of electron ion pair creation. It should be pointed out that taking into account both the ionization and the excitation of the Ne atoms and H₂ molecules, E_{ion} and ν_{ion} must be replaced in (22) by E_{ei} and $\nu_{\text{eff}} = \nu_{\text{ion}} + \nu_{\text{exc}}$ respectively. Here ν_{exc} is effective excitation frequency, including all excited states.

$$f_{\text{ion}}(\varepsilon) \cong \frac{I_0}{E_{\text{ei}} \nu_{\text{eff}}(\varepsilon) \sqrt{\varepsilon}}. \quad (24)$$

As it can be seen from (24) at energies $\varepsilon \gg E_{\text{ion}}$ up to the cathode fall U the EEDF decreases slowly.

At energies near the thresholds of ionization and dissociation only an estimation of the EEDF could be made. The decomposition in a series on a power of $E_{\text{ion}}/\varepsilon$ and $E_{\text{diss}}/\varepsilon$ is not correct. Nevertheless the behavior of the EEDF near the thresholds could be obtained in a similar way

$$f(\varepsilon) \cong \frac{C}{E_{\text{ei}} \nu_{\text{eff}}(\varepsilon) \sqrt{\varepsilon} + E_{\text{diss}} \nu_{\text{diss}}(\varepsilon) \sqrt{\varepsilon} + E_{\text{vib}} \nu_{\text{vib}}(\varepsilon) \sqrt{\varepsilon}} \quad (25)$$

where C could be determined from the expression $f(\varepsilon) = f_{\text{ion}}(\varepsilon)$ when $\varepsilon \gg E_{\text{ion}}$. So for C it is obtained $C = I_0$.

Using (25) an analysis near the threshold of dissociation and ionization could be made. At energies $\varepsilon < E_{\text{diss}}$ $f(\varepsilon) \cong \frac{I_0}{E_{\text{vib}} \nu_{\text{vib}}(\varepsilon) \sqrt{\varepsilon}}$ because $\nu_{\text{diss}}(\varepsilon) = 0$ and $\nu_{\text{ion}}(\varepsilon) = 0$.

Above this threshold $f(\varepsilon) \cong \frac{I_0}{E_{\text{diss}} \nu_{\text{diss}}(\varepsilon) \sqrt{\varepsilon} + E_{\text{vib}} \nu_{\text{vib}}(\varepsilon) \sqrt{\varepsilon}}$ and assuming that $\nu_{\text{diss}}(\varepsilon) \cong \nu_{\text{vib}}(\varepsilon)$ and $E_{\text{diss}} \gg E_{\text{vib}}$ it can easily be seen that a strong dissociation takes place and EEDF falls rapidly. The behavior of the EEDF near the threshold of ionization is the same.

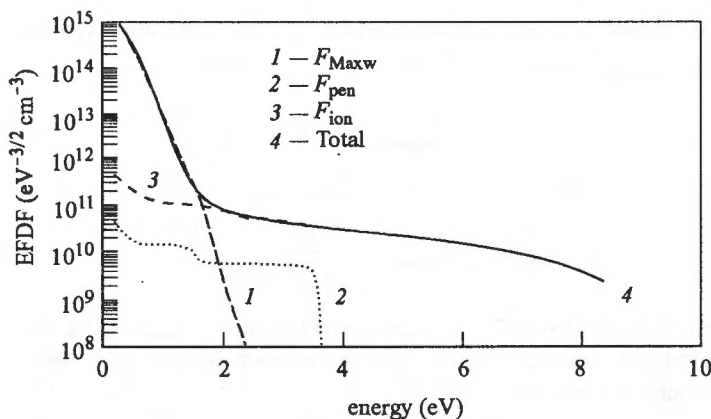


Fig. 1. Dependence of EEDF on the electron energy at Ne pressure of 3 Torr, H₂ pressure of 20 Torr and peak discharge current of 200 A

The EEDF shaping as a result of the particular elementary processes contributions under discharge conditions: 200 A peak current, 1500 V peak voltage, 3 Torr Ne pressure and 20 Torr H₂ pressure, is shown in Figs 1 and 2. The plasma parameters are: $3 \times 10^{14} \text{cm}^{-3}$ electron density and 0.23 eV electron temperature. The total value of Ne(1s) and Ne(2p) population is estimated to be $5 \times 10^{10} \text{cm}^{-3}$ and the electric field strength 1 V/cm. At $\varepsilon < E_{\text{diss}}$ the EEDF is Maxwellian up to energy 2 eV and step-wise between 2 eV and E_{diss} (Fig. 1). At energies $\varepsilon \cong E_{\text{diss}}$ a strong dissociation of H₂ begins and EEDF drops step-wise (Fig. 2). At energies $\varepsilon \cong E_{\text{ion}}$ the EEDF has analogous behavior. At energies $\varepsilon \gg E_{\text{ion}}$ the EEDF decreases proportionally to $\frac{1}{\sqrt{\varepsilon}}$.

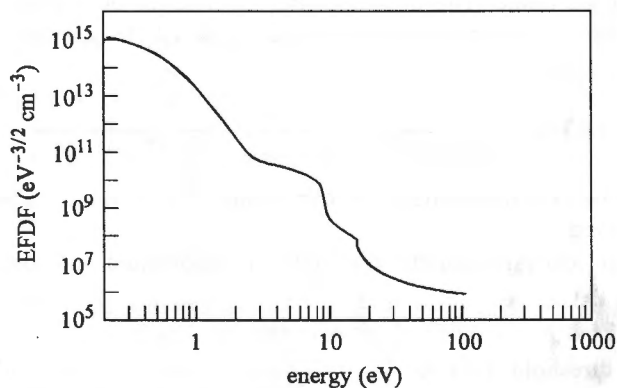


Fig. 2. Dependence of EEDF on the electron energy at Ne pressure of 3 Torr, H₂ pressure of 20 Torr and peak discharge current of 200 A

5. Calculation of the Rate Constant for Negative Hydrogen Ion Formation

Using the calculated EEDF an estimation for the elementary processes contributions to the inversion population formation in a hollow cathode Ne-H₂ Penning Recombination Laser can be made. The ion-ion recombination of negative hydrogen ion and positive neon ion could be an important mechanism for the upper laser level population. The rate constant is basically high because unlike the two-electron and dissociative recombination the presence of a third particle or molecular ion formation, respectively, is not necessary. Therefore, the idea of creating a laser whose upper laser level is populated through ion-ion recombination is very attractive [18].

The most possible reaction for H⁻ creation is the dissociative attachment



The threshold energy for this reaction is $\Delta E \cong 3.75$ eV, and the cross-section is about 10^{-21} cm² [19]. As it can be seen, the H⁻ production is a process which has a comparatively high threshold energy, so it is important to know the real amount of electrons capable to take part in this reaction. Using (13)–(15), the rate constant for H⁻ creation can be written as

$$k = 1.2 \times 10^{-13} \sqrt{T_e} \frac{\beta^2}{11 + \beta} e^{-\beta} + 9 \times 10^{-18} \text{ cm}^{-3}/\text{s} \quad (27)$$

where $\beta = \frac{\Delta E}{T_e}$.

The first term in (27) gives the contribution of the Maxwellian EEDF (13) and the second term — the contribution of the Penning (14) and direct (15) ionizations. The dependence of k on the electron temperature is plotted in Fig. 3. As it can be seen, at low $T_e < 0.3$ eV (typical for the Penning Recombination Laser) the real EEDF has to be taken into account.

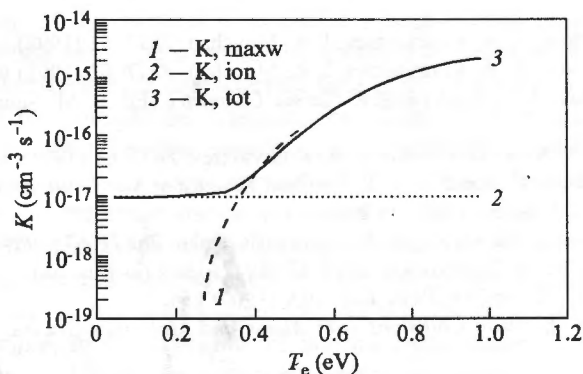


Fig. 3. Dependence of rate constant for negative ion formation K on the electron temperature at Ne pressure of 3 Torr, H₂ pressure of 20 Torr and peak discharge current of 200 A

6. Conclusions

The EEDF formation is analyzed in the case of HCD at intermediate pressures, high voltage and high electron densities in a Ne-H₂ gas mixture. It is shown that the EEDF consists of Maxwellian part up to energies of several T_e and has a stepwise form at energies higher than the dissociation potential of H₂ molecule. The characteristic formation of the EEDF is in local approximation.

The generation of negative hydrogen ions in a Ne-H₂ HCD is estimated by means of the calculated EEDF. It is shown that at $T_e < 3.0$ eV the knowledge of the real EEDF is essential to make correct calculations of the amount of the negative hydrogen ions in the high current hollow cathode plasma at intermediate pressures.

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